Elliptic flow of light nuclei in Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV

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Abstract

We present the elliptic flow (v_2) of light nuclei at mid-rapidity in Au+Au collisions at $\sqrt{s_{NN}} =$ 200 GeV. The results are measured in the STAR experiment at RHIC. The v_2 measurement for light nuclei as a function of transverse momentum p_T is found to follow an approximate atomic mass number (A) scaling. We compare the measured nuclei v_2 to results from a dynamical coalescence model calculation. The v_2 values for light nuclei are further scaled to the number of constituent quarks (NCQ) of their constituent nucleons and are consistent with NCQ scaled v_2 for baryons and mesons. The dominance of partonic collectivity in the transverse expansion dynamics in these collisions naturally produces such a consistent picture. Similar to other hadrons, an increase of p_T-integrated v_2 scaled by the participant eccentricity as a function of collision centrality has been observed.

1. Introduction

One of the most important experimental findings at RHIC has been the signature of coalescence as the mechanism of particle production. The differences in baryons and mesons at the intermediate transverse momentum ($1.5 < p_T < 5$ GeV/c) for observables like the nuclear modification factor and the elliptic flow parameter have been attributed to be the signatures of quark coalescence as a mechanism of hadron production [1]. However, it is experimentally difficult to study how local correlations and energy/entropy play a role in coalescence at the partonic level since the constituents are not directly observable. In relativistic heavy-ion collisions, light nuclei and anti-nuclei are formed through coalescence of nucleons and anti-nucleons [2,3]. The binding energy for the light nuclei are small, hence this formation process can only happen at a late stage of the evolution of the system when interactions between nucleons and other particles are weak. This process is called final-state coalescence [2,4]. The coalescence probability is related to the local nucleon density. Therefore, the production of light nuclei provides an interesting tool to measure collective motion and freeze-out properties. The advantage of nucleons

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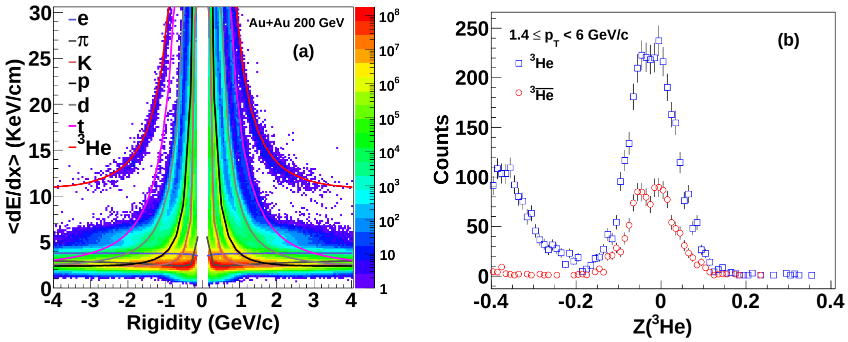

Fig. 1. (a) TPC dE/dx as a function of rigidity. Lines are exepected dE/dx values for different charged tracks predicted by the Bichsel function [10]. (b) Z distribution of ^3He (open square) and $\overline{^3He}$ (open circle). See the text for details.

over the partonic coalescence phenomena is that both the nuclei and the constituent nucleon space-momentum distributions are measurable quantities in heavy-ion collisions. By studying the elliptic flow of nuclei and comparing to those of their constituents (nucleons), we will have a better understanding of coalescence process for hadronization.

2. Experiment and analysis

The data presented here are obtained from Au+Au collisions at $\sqrt{s_{NN}} = 200$ GeV with the STAR detector at RHIC in the year 2007. STAR's main Time Projection Chamber (TPC) [8] was used for tracking and identification of charged particles. A data sample of 62 million minimum-bias triggered events (0-80% centrality) is used for this analysis. Figure 1 presents the particle identification techniques and methods. Panel (a) shows the ionization energy loss (dE/dx) of charged tracks as a function of rigidity ($rigidity = momentum/charge$) measured by the TPC at $-1 < \eta < 1$. Panel (b) shows Z ($Z = \log((dE/dx)|_{measure}/(dE/dx)|_{predict})$) distribution for ^3He and $\overline{^3He}$ signals for $1.4 \leq p_T < 6$ GeV/c, where $(dE/dx)|_{predict}$ is the dE/dx value predicted by the Bichsel function [9,10]. After tight track quality selections, the $^3He(\overline{^3He})$ signals are essentially background free. We derive the yields by counting $^3He(\overline{^3He})$ candidates with $|Z(^3He)| < 0.2$.

3. Results

The elliptic flow parameter, v_2, is the second order Fourier coefficient of the azimuthal distribution of the produced nuclei relative to the reaction plane of the initial nucleus-nucleus collision. The event-plane method was used to obtain the v_2 of nuclei [11], with the event plane resolution used for correction (calculated using the sub-event method [11]) being 73% for minimum bias triggered events. In the following discussions only statistical errors will be shown.

The left panel of Fig. 2 shows v_2 as a function of p_T for $\bar{t}$ and $^3He + \overline{^3He}$ in minimum-bias (0-80% centrality) collisions. The v_2 of $\bar{t}$ is shown only for $0.3 < p_T < 1.2$ GeV/c.

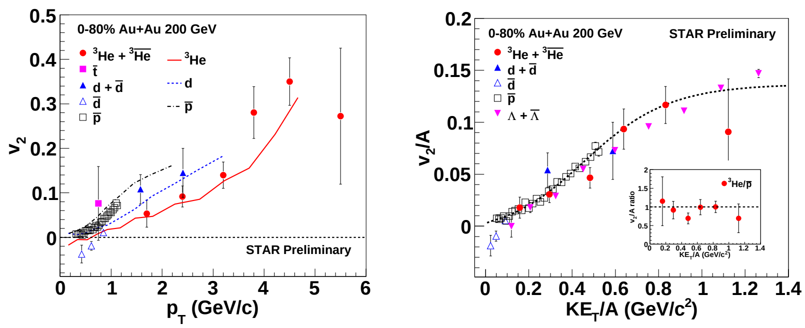

Fig. 2. Left panel: v_2 as a function of p_T for $\bar{t}$ and ^3He+$\overline{^3He}$ from 0-80% of the collision centrality. $d(\overline{d})$ and $\overline{p}$ v_2 are shown in the plot as a comparison [12] . The v_2 calculations from dynamical coalescence model are shown in different lines. Right panel: $d(\overline{d})$ and ^3He+$\overline{^3He}$ v_2 as a function of KE_T, both v_2 and KE_T have been scaled by A. $\overline{p}$ (open square) and $\Lambda+\overline{\Lambda}$ (solid inverted triangle) v_2 are shown in the plot as a comparison. The dotted line is a fit to the v_2 of $\overline{p}$. The insert is the ratio of ^3He+$\overline{^3He}$ to $\overline{p}$

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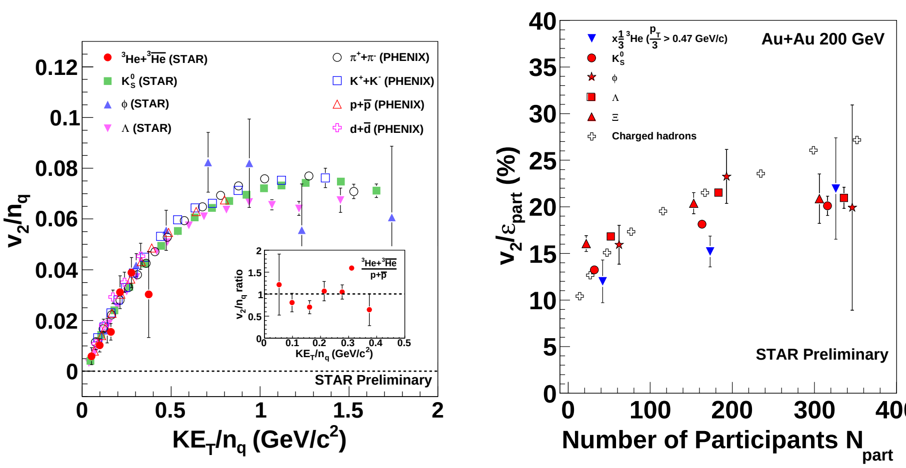

Fig. 3. Left panel: v_2/n_q as a function of KE_T/n_q for different particles. The insert is the ratio of ^3He+$\overline{^3He}$ to $p+\overline{p}$. Right panel: v_2/ε as a function of centrality for different particles, the ^3He value is scaled down by a factor of 3.

In the future, high statistics data sets and good particle identification using STAR TPC and TOF (Time-of-Flight) will allow us to study the p_T dependence of v_2 for $t(\bar{t})$. The v_2 of $\overline{p}$ and $d(\overline{d})$ measured by the STAR [12] are also shown for the comparison. The v_2 of $p(\overline{p})$, $d(\overline{d})$ and $^3He(\overline{^3He})$ are well described by the dynamical coalescence model [13]. In this model, the probability for producing a cluster of nucleons (d, t and ^3He) is determined by the overlap of its Wigner phase-space density with the nucleon phase-space distributions at freeze-out. To determine the Wigner phase-space densities of the d, t and ^3He, we take their hadron wave functions to be those of a spherical harmonic oscillator. The coordinate and momentum space distributions of hadrons at freeze-out

are obtained from AMPT model calculation [14].

The results with both v_2 and transverse kinetic energy $KE_T = m_T - m$, where $m_T = \sqrt{p_T^2 + m^2}$ scaled by A are shown in the right panel of Fig. 2. As a comparison, the $\overline{p}$ and $\Lambda + \overline{\Lambda}$ v_2 [12] are superimposed on the plot. The data suggest that the $^3He(\overline{^3He})$, $d(\overline{d})$ and baryon v_2 seem to follow the A scaling within errors, indicating that the light nuclei are formed through the coalescence of nucleons just before thermal freeze-out.

The left panel of Fig. 3 shows v_2/n_q as a function of KE_T/n_q for different hadrons inluding the nuclei and anti-nuclei, where n_q is the number of constituent quarks. The value of n_q used for $d(\overline{d})$ and $^3He(\overline{^3He})$ are 6 and 9 respectively, to account for their composite nature. The scaled results for v_2 versus KE_T for the light nuclei and anti-nuclei are consistent with the experimentally observed NCQ scaling of v_2 for baryons and mesons [15]. This is also consistent with the picture that partonic collectivity dominates the transverse expansion dynamics of the nucleus-nucleus collisions at RHIC. The right panel of Fig. 3 shows the centrality dependence of the ratio of the integrated v_2 over the eccentricity (v_2/ε_{part}) for charged hadrons, K_s^0, ϕ meson, Λ, Ξ and ^3He. The v_2 of ^3He is integrated over the measured p_T range (i.e. $p_T > 1.4$ GeV/c) and scaled down by a factor of 3. This ratio (v_2/ε_{part}) to some extent reflects the strength of the collective expansion. For more central collision, the larger value of this ratio indicates a stronger collective expansion.

4. Summary

We have measured the v_2 of light nuclei using the particle identification capability of the STAR TPC detector. The v_2 values of the light nuclei when scaled by atomic mass number A, follows the baryon v_2, which supports the idea of the light nuclei formation through the coalescence of nucleons just before thermal freeze-out. The v_2 of light nuclei from the dynamical coalescence model agree well with the data. The v_2 as a function of the transverse kinetic energy follows a scaling with the number of constituent quarks n_q.

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